2. The use of scheduling performance criteria in practice

This chapter discusses the use of scheduling performance criteria in practice. Whereas, in literature, scheduling performance is often limited to measures for assessing the anticipated execution of the schedule, our empirical data show that alongside these criteria, firms often use metrics to assess the performance of the organizational process that leads to the schedule. In addition, the findings indicate that an important aspect of the performance of the scheduling process, namely responsiveness, is often deemed more important than optimizing the schedule in many firms, especially in firms that face uncertainty during schedule execution. The chapter contributes to planning and scheduling research by categorizing scheduling performance criteria that are used in practice. The chapter supports managers in selecting appropriate scheduling performance criteria under various business conditions.[6]

2.1 Introduction

One of the frequent questions that firms address during academic research projects is how should scheduling performance be measured and managed, and, related to this, which criteria should be used to assess the task performance of schedulers. It seems that the metrics commonly discussed in scheduling literature, such as maximum completion time, cost, total waiting time, productivity, and (service) delivery rates (Leung 2004; Pinedo 2008) are considered insufficient in practice.

During recent decades, a considerable increase in the study of performance measurement has been witnessed (Neely 1999; Evans 2004; Melnyk et al. 2004; Neely 2005; Lehtinen and Ahola 2010). Whereas the majority of the research focuses on performance measurement on the firm level, several authors have investigated department- and business function- specific performance measurement, proposing a variety of metrics for sales, marketing, new product development, manufacturing, and distribution (Neely et al. 1997; Lohman et al. 2004). Interestingly, scheduling has a large effect on business performance, such as the efficiency and flexibility of a firm, by determining its order lead times, delivery flexibility, machine and material usage, and staff workload (Leung 2004; Van Wezel et al. 2006b; Zwikael and Sadeh 2007; Pinedo 2008). However, performance measurement of scheduling has received far less attention than other business functions (Kempf et al. 2000; De Toni and Tonchia 2001; MacCarthy and Wilson 2001; McKay et al. 2002).

[6] A revised version of this chapter has been accepted for publication: De Snoo, Van Wezel, and Jorna (2011a). An empirical investigation of scheduling performance criteria. Journal of Operations Management, in press. An earlier version of this chapter has been presented during the annual meeting of the Academy of Management in Chicago, USA, August 2009 (De Snoo et al. 2009).

As with all organizational functions, appropriate performance criteria or metrics are needed to measure and manage scheduling performance. Neely et al. (2005) define a performance measure as "a metric used to quantify the efficiency and/or effectiveness of an action" (p. 1229). In general, effective metrics make sense to the people using them and are value-oriented, that is, they are linked to how the measured activity delivers value to its stakeholders (Neely et al. 1997; Melnyk et al. 2004; Lehtinen and Ahola 2010). In the projects reported in this chapter, we have empirically investigated and analyzed scheduling performance metrics from this perspective, resulting in the development of a set of scheduling performance criteria that enrich the metrics reported currently in scheduling research. In this way, the chapter theoretically contributes to scheduling and performance measurement literature and practically supports managers in developing scheduling performance measurement systems.

Two sequential empirical research projects are reported. In Study 1, we extensively interviewed 86 managers and planners in 43 organizations to establish criteria that firms use to measure scheduling performance. Based on this, a classification framework of performance metrics is presented, extending existing scheduling research and providing a first step toward distinguishing the types of performance criteria that can be used to assess scheduling performance. Further, an important outcome of the first study is a partial answer to the question posed in performance measurement literature as to whether measures should focus on processes (i.e., the actual actions), on the output of processes, or on both (Neely et al. 2005). Based on the results, we concluded that, with scheduling, both process and output are important. However, although a high performance in terms of both output and process criteria will be relevant in many scheduling situations, the *relative* importance of the two types of performance criteria varies between firms. Therefore, in Study 2 we investigated the conditionality of the output/process focus through a survey involving 125 organizations.

The chapter continues in Section 2.2 by discussing the theoretical background to the research. Sections 2.3 and 2.4 describe the motives, design, data, analyses, and results of Study 1 and Study 2 respectively. Finally, Section 2.5 discusses the main contributions from the studies and draws conclusions.

2.2 Theoretical background

To investigate scheduling performance, the function and contribution of scheduling within a firm should first be understood. Therefore, this section starts by explaining the organizational

context of scheduling. Following this, the mainstream perspectives on scheduling performance are outlined. Finally, an overview of the research questions is provided.

2.2.1 The organizational context of scheduling

Scheduling is the activity of allocating and tuning a firm's resources, such as the workforce, machines, vehicles, and material, and the tasks or activities to be executed within a certain period (Leung 2004; Pinedo 2008). Schedules show the result of this allocation process. The scheduling process encompasses a variety of activities (compare Fig. 1.2), such as information gathering and interpretation, communication and negotiation with different stakeholders, puzzle solving, decision-making, and problem solving (McKay et al. 1995a; MacCarthy et al. 2001; Jackson et al. 2004; Kreipl and Pinedo 2004; McKay and Wiers 2006; Van Wezel et al. 2006a). Information about available resources and (client-specific) task demands has to be gathered and interpreted. Further, information about the goals and constraints the schedule should obey is needed to create a good schedule. Various departments (as stakeholders of the scheduling function) could set different and even conflicting goals and constraints, for instance regarding production lead times, service costs, and staff workload. Schedulers have the task of balancing these different interests, and, therefore, they have to communicate and negotiate with these stakeholders. Within the puzzle-solving activity, alternative schedules are developed and a choice is made based on a number of criteria within the decision-making activity (discussed in Section 2.2.2 below). Given that many occurrences can disturb the execution of the schedule as planned, schedulers have to adapt the schedules frequently (Aytug et al. 2005). Rescheduling can involve the same range of activities as scheduling: new information has to be gathered, managers have to be informed and convinced to change orders, a choice from the alternative solutions has to be made, et cetera, but rescheduling typically takes place under stricter time constraints. Interestingly, most research in scheduling focuses on methods and techniques to support solving the scheduling puzzle. As we will discuss, this has resulted in scheduling performance measures in the literature that one-sidedly focus on this activity.

2.2.2 Scheduling performance in scheduling literature

Much scheduling research concentrates on improving existing methods for specific classes of scheduling situations using techniques often drawn from Operations Research and Artificial Intelligence (Leung 2004; Brucker 2007; Pinedo 2008; Sule 2008). Recent literature reviews

illustrate this development of scheduling methods for problems in a wide variety of domains such as production scheduling (Potts and Kovalyov 2000; Hoogeveen 2005; Allahverdi et al. 2008), project scheduling (Herroelen and Leus 2005), nurse scheduling (Cheang et al. 2003), operating room scheduling (Cardoen et al. 2010), outpatient scheduling (Cayirli and Veral 2003), and school bus routing (Park and Kim 2010). In most methods and techniques, scheduling performance is measured as the extent to which the scheduling goals are realized and the constraints are not violated. Metrics commonly used to measure scheduling performance are related to the projected execution of the schedule. For example, in production scheduling, these can include total completion time, lateness, earliness, tardiness, and machine utilization (Hoogeveen 2005). In workforce scheduling, metrics include total penalty cost due to violating shift balances and total satisfaction of employees' preferences (Cheang et al. 2003), and in patient appointment scheduling, these include doctor's productivity and idle time, total waiting time and average flow time of patients (Cayirli and Veral 2003). Within these studies, the assessment of performance is based on certain characteristics of the schedule. In other words, scheduling performance measures assess the quality of the anticipated execution of the schedule. Several authors have criticized this as being a too narrow focus; their main criticisms are discussed in the next subsection.

2.2.3 Toward a broader perspective on scheduling performance

As discussed in Section 2.2.1, there is more to scheduling than mathematically solving a well-defined problem. Empirical studies describing the scheduling process show that the information on which the schedule is based needs interpretation, that goals may require different weightings at different times, and that disturbances may result in negotiations between department managers that cannot be formalized (McKay et al. 1995a; MacCarthy and Wilson 2001; Jackson et al. 2004; Kreipl and Pinedo 2004; Van Wezel et al. 2006a; Berglund and Karltun 2007). In these studies, scheduling performance has often been approached broadly: each of the scheduling activities is seen as contributing to scheduling performance. However, explicit reference in the literature to measuring the performance of scheduling activities is scarce. MacCarthy et al. (2001) remark that "objective measurement in planning, scheduling and control must account for the process by which plans are generated and executed, the people who are instrumental in generating them as well as the actual realization of plans and schedules over time" (p. 312). Jackson et al. (2004) note that the performance measures in their case studies "took the form of contextual expectations generated by other

business personnel. Such performance measures represented the way that schedulers were expected, for example, to be good communicators, to share accurate and up-to-date information, to solve problems, and to have a proactive view of requirements" (p. 548).

However, apart from such anecdotes in case studies, there is no structured knowledge on what scheduling performance constitutes in practice or how performance management regarding scheduling takes place. Consequently, it is not clear whether scheduling performs poorly, adequately, or even well in any given situation. Therefore, in order to design performance measurement systems for scheduling, explicit research into performance criteria is needed (MacCarthy et al. 2001). In this chapter, a first step toward answering the overall question 'What constitutes scheduling performance in practice?' is provided by describing two empirical studies. The central question in Study 1 is 'Which criteria do firms use to assess scheduling performance?' The central question in Study 2 is 'When do firms use certain types of scheduling performance criteria?'

2.3 Study 1: Identifying scheduling performance criteria

2.3.1 Research process

The data collection in Study 1 took place in two phases. Initially, Study 1 was designed to investigate organizational variables that determine scheduling performance using a descriptive survey design (Forza 2002). By using the 'structure-environment' perspective (Aksin and Masini 2008), we intended to uncover 'organizational configurations of scheduling processes' and the circumstances or contextual conditions under which these configurations lead to high scheduling performance. In this way, the aims and the design of the research were developed along similar lines to studies investigating the relationship between manufacturing practices and firm performance, a field recently reviewed and classified as OM practice contingency research by Sousa and Voss (2008). Data from a variety of firms were collected, including data on their planning and scheduling structure and environment, and the metrics used to assess scheduling performance. Respondents could select metrics from a prepared list, and also add metrics that were used but not listed. Firms used this latter option much more often than we had expected. Our provided list of performance metrics was based on the scheduling literature (see Section 2.2.2), but appeared to be far from complete. Many respondents indicated that they used other criteria, and that the criteria on the list were not always useful. Given this research finding, we concluded that a better understanding and operationalization of the 'scheduling performance' concept itself was needed *before* possible organizational

antecedents for scheduling performance could be determined. Having concluded this, we altered the research design.

To thoroughly understand the meaning of scheduling performance in business practice, it was decided to hold a number of in-depth interviews in a supplementary project (Phase 2). To prevent response bias and to ensure the collection of a wide variety of performance measures, the research design needed to be open and exploratory. Consequently, we followed the methodological guidelines that are proposed for exploratory survey research (Malhotra and Grover 1998; Forza 2002) and building theory from cases (Eisenhardt and Graebner 2007). Guidelines for grounded theory development (Locke 2001; Pagell 2004; Corbin and Strauss 2008) were also incorporated during the data analysis activities. The data collection process resulted in a large amount of qualitative data concerning scheduling performance criteria from a variety of firms. Once this data were analyzed, the data from the initial data collection activities (Phase 1) could be reused to validate and enrich the findings from Phase 2.

2.3.2 Data collection

Within Phase 1, over 50 firms were approached to investigate possible organizational determinants of scheduling performance. Firms were selected based on the expected scheduling situation in order to sample a rich set of scheduling situations in terms of the type of scheduling, the kind and the number of resources being scheduled, the goals and constraints being considered, and the organizational context. Thirty-six firms were willing to participate. Four of these firms did not fit our sample criteria, in most cases because the key respondent was not actively involved in scheduling activities. In each of the remaining 32 organizations, two people were asked to fill out the survey: a scheduler and a manager. Mostly, the latter was the manager of the scheduled process, for example, the production manager. Therefore, the first phase of Study 1 resulted in a set of 64 usable data reports from 32 different organizations. The face-to-face survey was filled out with a researcher present enhancing the confidence that data collection instructions were followed as intended and providing opportunities to explain complex questions (Forza 2002). Each session took, on average, 75 minutes. The two sessions were held sequentially: the manager did not attend the session with the scheduler and vice versa. Three researchers held the surveys; to prevent researcher bias, the survey contained an exhaustive explanation and the researchers met several times to discuss the survey. Appendix 2A provides the survey topics used in Phase 1.

For the interviews in Phase 2, eleven other organizations were approached to gain an in-depth and richer understanding of the meaning of scheduling performance. In each organization, a scheduler and a person who used the schedule were interviewed. In a few cases, managers were also interviewed. Open questions were used, and the interviewees were probed thoroughly. Appendix 2A-II provides a list of the face-to-face, exploratory survey topics used in Phase 2.

Table 2.1 provides a summary of the cases used and the types of scheduling that the interviewed schedulers were tackling (Appendix 2B provides a detailed overview of all cases). Several schedulers were developing various types of schedules, although these were often related. For example, a call-center scheduler was scheduling both the sequence of projects and employee shifts (production and staff scheduling), and a scheduler in a manufacturing firm was scheduling both production and transport activities. Of the 21 schedulers from manufacturing firms interviewed, all were involved in production scheduling, one was also involved in staff scheduling, and four were also involved in route planning or distribution scheduling.

Table 2.1 Cases in Study 1

Firm type	Number of cases	Production scheduling	Staff scheduling	Route planning
Manufacturing	21	21	1	4
Transportation	7	3	6	4
Service	15	6	14	1
Total	43	30	21	9

2.3.3 Data analysis

The interviews were transcribed to enable quote analysis, which was carried out using an open coding system (Miles and Huberman 1994): that is, no restrictions were put on the amount or phrasing of the codes. Further, single data incidents were consciously coded in various ways to elaborate possible different meanings of a quote (Locke 2001). Simultaneously, a rough list containing all the codes was developed; additions and refinements to the list were triggered by the continuing process of jointly coding and analyzing the data. This constant comparative method offered "a logic for composing conceptual elements that hinge on their articulation through close reading, comparison, and attendant conceptualization of data" (Locke 2001: 45). Whereas the first step in this method involves naming and comparing the data incidents, the second step aims to develop a conceptual scheme. The research activities followed the pattern described by Pagell (2004): the process of combining, renaming, and redefining led to

trying a number of different categorizations of the criteria. In this way, a model and a categorization of scheduling performance criteria were developed based on the final list of codes. The categorization was evaluated by returning to the data collected in Phase 1. Finally, the model was further refined and adapted following several discussions with experts from industry and academia.

2.3.4 Results

The interviews resulted in a rich collection of views on metrics for scheduling performance. Table 2.2 contains a few sample quotes about scheduling performance from the interviewees (a fuller overview of quotes from all respondents can be found in Appendix 2C). The table represents an intermediate step in the coding and classification procedure for the quotes. The first step in this procedure involved coding quotes related to factors that influence but do not measure scheduling performance (column headed 'factors influencing scheduling performance'). Subsequently, the remaining quotes about scheduling performance measures were split into two groups: quotes clearly representing well-known performance measures like due date reliability, cost, and resource utilization (column 'criteria on the scheduling product'), and the remaining criteria (column 'indirect scheduling performance criteria'). Finally, particularly insightful quotes related to scheduling performance were put in a separate column (column 'other significant quotes').

After this initial classification, quotes and categories were analyzed in more detail. On the highest level, we made a distinction between performance criteria, factors influencing scheduling performance, and other specific quotes. For instance, the response speed of a scheduler to a request from an operator was classified as a performance criterion, whereas the physical distance between the scheduler and the schedule user was classified as an influencing factor. Within the group of performance criteria, we made a further distinction based on the focus of the criteria. Criteria often appeared to be focused either on the scheduling *product* or on the scheduling *process*. The scheduling *product* is the schedule as provided to the employees executing the schedule, including operators using the production schedule, truck drivers using the route plan, and nurses using the staff schedule. The scheduling product is the information product resulting from the scheduling process, and it encompasses the final schedule and all other relevant information such as schedule adaptations. The scheduling *process* is the set of activities to develop, adapt, and communicate schedules.

Criteria that could not be clearly placed in either of these two categories were placed in a separate group. Figure 2.1 shows the final scheduling performance criteria framework including the 16 types of performance criteria within these three main classes. Each of these is discussed in the following subsections. Factors influencing the scheduling process are briefly discussed in Section 2.3.4.4.

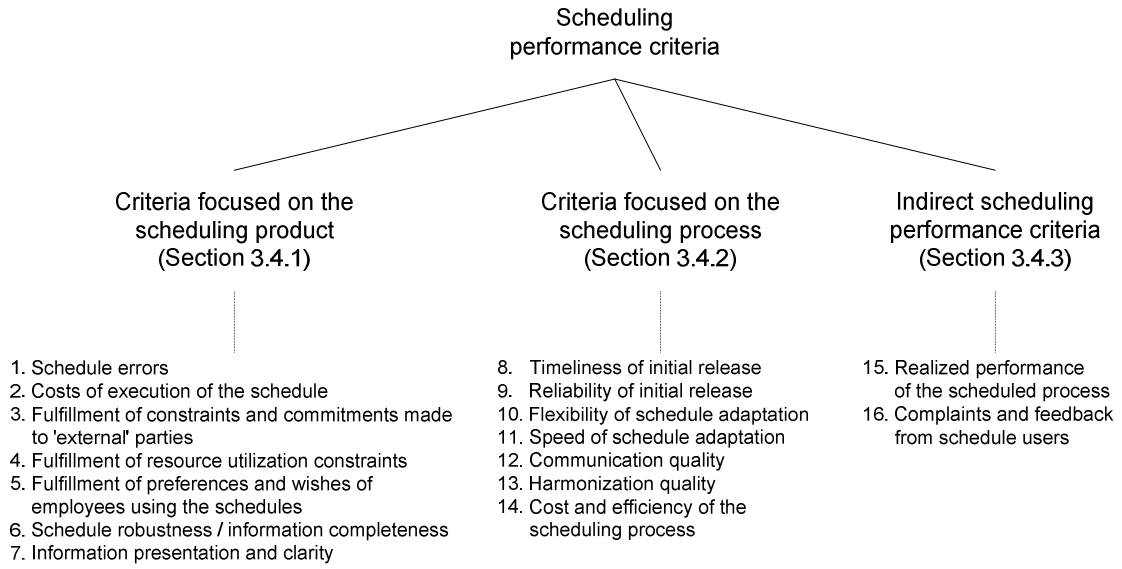

Figure 2.1 Scheduling performance measures framework

2.3.4.1 Measures focused on the performance of the scheduling product

The first category of metrics as used by the interviewed firms consists of performance criteria relating to the scheduling product. As indicated above, the scheduling product is the output of the scheduling process and includes the schedule and other relevant information. Within this group of metrics, seven sub-categories could be distinguished.

First, scheduling performance is sometimes evaluated by considering the number and severity of schedule errors. Schedule errors are incorrect scheduling decisions that lead to infeasibility in the execution of the schedule. Such errors are, for instance, a wrong production routing, overloading transport vehicles, or the allocation of one person to multiple jobs to be performed at the same time. Errors occur in all types of schedules: sometimes they occur because of a lack of adequate information but, in all cases, they decrease scheduling performance.

Table 2.2 Example quotes on scheduling performance from Study 1 Phase 2

Type of respondent	Criteria on the scheduling product	Other scheduling performance criteria	Factors influencing scheduling performance	Other significant quotes
Production planner in a manufacturer of shavers	* Satisfy production constraints. * Wishes of production should be taken into account.	* Plans should not change too often. * The planning quality is good if the plan is accepted by production without grumbling.	* If a supplier cannot deliver material, the planning quality decreases because the plan is not reliable (no stable production).	* If suppliers could always deliver and if there were few constraints and restrictions on the production of different products, it would be the most beautiful situation. Little uncertainty results in few plan changes…
Manager of planning office at an amusement park	* Shifts have to be filled as much as possible. * The planning is good if all shifts are filled with employees having the right qualifications. * Preferences of employees have to be taken into account. * Fixed-contract employees should not be scheduled on shifts for temporary employees (to avoid high costs). * An acceptable plan deviates from a good plan by a maximum of 5%.	* Planning performance is assessed on the staff costs during plan execution, and on the number of complaints that I receive from planned employees. * I judge the planning based on messages from the planners and the departmental managers. In addition, I judge it based on complaints from the employees themselves. This is more based on feeling than on numbers.	* Information about staff availability should be present on time. For instance, if data about educational duties become available too late, plans have to be changed after release, and the planning can never become as good as before. * There are too many constraints (e.g., safety requirements, maximum budget, and maximum number of temporary personnel).	* Fulfilling all job qualification requirements does not guarantee a good execution of the staff schedule. For instance, one duo can form a 'dream team', whereas another duo cannot collaborate at all. Thus, the planner has to take into account human characteristics alongside basic qualifications.
Manager of the sales & planning department at a pipe manufacturer	* Good scheduling is making optimal use of resources. * The operators judge the scheduling performance on the number of setups.	* The scheduling performance is judged on the collaborative behavior of the planner (with production), the transferability of the planner's tasks, the correctness of data, the extent of correct rejection of orders, and the stability of schedules. * The operators judge the scheduling performance also on the level of 'challenge' in the work, the number of plan changes, and the time pressure.	* The scheduler needs clear performance guidelines; it is bad if he/she is judged on flexibility whereas it was agreed that he/she would be assessed on production quantity. Performance criteria should be mutually understandable and consequent.	* Production performance indicators and planning performance indicators are mixed up a bit here. A production indicator is of course not a planning indicator. Because quantitative measures are lacking, I qualitatively judge the quality of scheduling based on these questions: - Is the scheduler communicating correctly? - Does the scheduler collaborate with production? - Does an overall view exist? - Are the tasks of the scheduler transferable? - Are parameters and article data correct?
Staff and patient scheduler at a rehabilitation center	The schedules should enable: - a good program for the client - work variety for the doctor - sufficient patients to realize targets - short waiting queues - high utilization rate of doctors.	* Scheduling performance includes the speed of plan adaptation. * The quality of scheduling is judged on the number of phone calls, emails, questions, and complaints about the scheduling.	* Insight into the availability and capacity requirements of doctors and a bird's-eye view enable high quality scheduling. * The short planning horizon leads to many last-minute adaptations, no-shows, etc.	* Good scheduling means realizing a balance between the interests of client, doctor, and management.
Staff and route scheduler at a road service provider	* Guidelines I have to obey include: - the driving time of the road service employee should not exceed 30 min; - the waiting time for the client should not exceed 90 min; - urgent situations and priorities have to be processed first.	* Even if there are many problems, plan quality is still sufficient if the plan users understand the situation and solutions. * Good scheduling results in an acceptable situation for the plan users.	* More rules (i.e., less decision latitude) for the plan users would improve the scheduling quality.	* Good planning differs from time to time. I have to balance various interests, while choosing the least bad solution. * Good scheduling is highly dependent on the environment: I am satisfied with the scheduling quality if I have reasonably dealt with all the problems, even if norms have had to be violated.

Second, almost all the firms used the costs of schedule execution as an indicator of scheduling performance. Costs included costs linked to material, staff, and machine use, and costs that were due to backorders or penalties because of late deliveries.

The third, fourth, and fifth groups of performance criteria encompass various types of constraint violations that influence scheduling performance. Constraints were often formulated as targets covering, for example, machine utilization, inventory levels, the level of tardiness, the team composition, the variety in staff activities, and the realization of financial budgets. 'External constraints' and 'resource utilization constraints' are distinguished here to highlight the fundamental difference. External constraints (Group 3) are commitments made to external parties such as clients, suppliers, and stakeholders, whereas resource utilization constraints (Group 4) are internal limitations set by the firm itself. The fifth group of performance criteria includes constraints that are linked to the preferences and wishes of the workforce executing the schedules. Many respondents emphasized that scheduling performance is influenced by the extent that the scheduler considers these preferences and wishes. The major distinction between constraint violations and schedule errors (Group 1) is that schedule errors require rescheduling by definition, whereas constraint violations may be tolerated.

The sixth group of criteria used to assess schedule performance is related to the stability of the schedule. Respondents indicated that schedule users appreciated a high predictability of the schedule; it should be changed as little as possible. Therefore, this group of criteria includes those related to the robustness and adaptability of the schedule, for instance because of disturbances and uncertainties.

Finally, several interviewees mentioned the understandability of the schedule and of schedule changes as a measure of scheduling performance (Group 7). They indicated that information presentation and clarity about potential choices and changes influence perceptions of scheduling performance. From these quotes, we concluded that it is not only *what* information is given, but also *how* this information is communicated that influences performance evaluation. We chose to categorize the performance of the communication process within the scheduling *process* performance criteria; this class of criteria is explained now.

2.3.4.2 Measures focused on the performance of the scheduling process

When schedulers, managers, and users of the schedule were asked how they viewed and assessed scheduling performance, they often started out by mentioning criteria that are related

to the scheduling process. The scheduling process consists of the set of activities that is used to develop, adapt, and communicate schedules and schedule changes. Seven additional groups of performance criteria used to measure scheduling performance could be distinguished.

Many respondents indicated that time is an important aspect; there should be enough time between initial schedule release and schedule execution (Group 8), and the moment of release should be reliable (Group 9). Furthermore, respondents emphasized that schedulers do not develop their schedules in isolation. Often, circumstances change and the schedule can or should be adapted. Most schedulers were expected to handle schedule adaptation requests alongside their main task of creating new schedules. Consequently, flexibility within the scheduling process was viewed as highly important (Group 10). Schedulers were expected to be accessible to discuss alternative solutions, and schedule adaptations requests should be handled fast (Group 11).

For scheduling performance, behavioral aspects are important also. Although in the end the balance in the interests of stakeholders can be found in the schedule itself (e.g., do we violate a due date or do we schedule overtime), respondents stressed that the negotiation and communication abilities of the scheduler are very important for both the acceptance of the initial schedule and the acceptance of schedule adaptations. Communication quality (Group 12) and harmonization quality (Group 13) are used as terms to specify the criteria related to these behavioral aspects.

Finally, the number of schedulers needed (staff cost), and the employability of schedulers on other tasks were used as indicators of scheduling performance. Further, schedulers in several firms were expected to use appropriate and efficient methods and systems that enabled good schedules to be created in short time. Thus, the costs and the efficiency of the scheduling process were used as performance criteria in measuring scheduling performance (Group 14).

2.3.4.3 Indirect measures of scheduling performance

Alongside measures used to assess aspects of the scheduling product or the scheduling process, several firms used measures that could not easily be attributed to either of these two categories.

First, quite a few respondents assessed scheduling performance with measures that seemed to be primarily designed for measuring the performance of the schedule users and of the scheduled process (Group 15). For example, one service organization used end-customer

satisfaction rates as an indicator of scheduling performance. Although these satisfaction rates are likely to be influenced by waiting times determined in the schedule and by the flexibility in the scheduling process to adapt client appointments, many antecedents of customer satisfaction, such as product quality and after-sales service, are clearly beyond the influence of the scheduler. Another firm used sickness rates of scheduled personnel as a measure of scheduling performance. The reasoning behind this measure was that if the working-time preferences of employees were ignored in scheduling, absenteeism would increase. Research has indeed shown that employees' health is negatively influenced by bad staff schedules (Thierry and Jansen 1998). However, again, many factors causing sickness are beyond the influence of the scheduler.

Second, several managers used (the amount of) complaints and feedback from the schedule users as an indicator of scheduling performance. Clearly, complaints and feedback can be related to problems in the schedule or to problems in the scheduling process. Therefore, we classified the criteria related to complaints and feedback within the class of indirect measures (Group 16).

2.3.4.4 Factors influencing scheduling performance

Alongside criteria used to measure scheduling performance, the respondents were also asked for factors that influenced scheduling performance. From the coding analysis, five key factors could be deduced. First, the firm's planning structure determines the tasks, roles, authorities, and decision latitude of the various planners and schedulers in a firm. For instance, possibilities to reschedule in order to improve already released schedules can be constrained by the planning structure. Second, a scheduler's knowledge and skills influence scheduling performance. Several respondents mentioned the importance of employing a scheduler with experience of working in the production process. Third, the availability and the use of information technology were reported as influential factors. A fourth factor was linked to the availability, reliability, and completeness of information. If a scheduler bases a schedule on inaccurate information, scheduling performance will never be high. Finally, the levels of complexity and uncertainty in the scheduling environment were considered to influence scheduling performance. For example, a high scheduling performance in terms of low setup costs is difficult to achieve if uncertainty results in disturbances requiring frequent schedule adaptations.

2.3.5 Summary, evaluation, and discussion

Table 2.3 summarizes the results from the analysis of the data obtained from the in-depth interviews and presents a few example quotes for each type of measure. To check the appropriateness of this classification, the use of these criteria in the firms previously surveyed in Phase 1 was investigated. The data reports from Phase 1 were re-analyzed, and the criteria mentioned by each of the respondents were placed within this classification. Appendix 2D provides an overview of the criteria and influencing factors that were mentioned by the planners, managers, and plan users participating in Phase 1. It should be noted that, in Phase 1, the respondents were asked to select criteria from a predetermined list and to add items if needed. However, they were not probed to provide a complete overview of all the performance measures they used, as in Phase 2. Consequently, the responses could have been incomplete. Nevertheless, the results did clearly show that firms use a wide variety of scheduling performance criteria, including both product- and process- oriented measures.

The results show that the term 'scheduling performance' is used in practice in a variety of ways. Sometimes, it means that the scheduling process has to result in a cheap schedule, or in a flexible schedule, in an adaptable schedule, or in a rapidly delivered schedule. In other situations, high scheduling performance is seen as meaning that schedulers are efficient negotiators, rapid adapters, and smart problem solvers, and that the scheduling process is organized in an efficient and flexible way. The process-oriented criteria show that scheduling is not only a 'production process', in which a schedule is created or adapted, but also a 'service process', in which information is collected and delivered, interests and trade-offs are discussed, and constraints or commitments are negotiated. Thus, alongside schedule-focused criteria, the functioning of the schedulers and the way in which scheduling activities are executed are important factors in determining scheduling performance. Criteria related to the scheduling process also demand managerial attention; therefore, these criteria should be incorporated in scheduling performance models and theory (MacCarthy and Wilson 2001). The proposed classification framework is a first step in distinguishing the types of performance criteria that can be used to assess scheduling performance.

Table 2.3 Overview of performance criteria for scheduling

Group	Criterion	Focus	Quotes from the respondents
1	Schedule errors	Product	The schedule contains correct processing times (PS). The schedule contains correct production routings (PS).
2	Costs of execution of the schedule	Product	Good scheduling is focused on low costs (SS). The schedule remains within financial budgets (PS).
3	Fulfillment of constraints and commitments made to 'external' parties	Product	Orders are delivered on time (PS). All shifts are filled, because all buses have to be driven (RP/SS). Projects are realized within time and costs (PS/SS).
4	Fulfillment of resource utilization constraints	Product	Scheduled shifts fit with labor laws (SS). Employees work a minimum number of hours a week (SS). Overtime and outsourcing are minimized (PS). Utilization rates are realized (PS). Number of setups and waiting times are minimized (PS/SS).
5	Fulfillment of preferences and wishes of employees using the schedules	Product	Preferences of employees regarding free days are taken into account (SS). Good scheduling means a good balance between the interests of the client, the doctors, and the management (SS).
6	Schedule robustness and information completeness	Product	The schedule is easily adaptable (PS). The number of critical links in the schedule is minimal (RP). The schedule is stable because of the time required to hire and train temporary workers (SS). Schedules should be as complete as possible (PS).
7	Information presentation and clarity	Product	A good schedule provides information about choices made by the scheduler (PS). Schedules should be clear, because employees want a fair allocation of free days (SS).
8	Timeliness of initial release	Process	The employees find it important that the plans are released timely (SS).
9	Reliability of initial release	Process	Schedules should be released on time (SS).
10	Flexibility of schedule adaptation	Process	The scheduler should be easily accessible to renegotiate schedule constraints (due dates, routings, rush orders) (PS).
11	Speed of schedule adaptation	Process	Schedule changes are communicated timely (SS). Schedulers should be able to serve the salespeople with a quick response to rush order requests (PS).
12	Communication quality	Process	The scheduler should be able to convince the employees that their feedback and/or preferences are taken into account (SS). The scheduler should not communicate each small adaptation to the shop floor (PS).

Table 2.3 (continued) Overview of performance criteria for scheduling

Group	Criterion	Focus	Quotes from the respondents
13	Harmonization quality	Process	The level of tact and the ability of schedulers to balance and communicate different stakeholder interests (PS). The scheduler should collaborate with production (PS).
14	Cost and efficiency of the scheduling process	Process	Schedules should be developed efficiently, to enable the scheduler to perform other managerial tasks (SS). The tasks of the scheduler are transferable (PS).
15	Realized performance of the scheduled process	Indirect	Absenteeism rates due to employee dissatisfaction with the schedules are an indicator of scheduling quality (SS). Good scheduling leads to satisfied clients (PS).
16	Complaints and feedback from schedule users	Indirect	Good scheduling means few complaints from employees (RP/SS). The quality of scheduling is judged on the number of phone calls, emails, questions, and complaints about the scheduling (SS).

PS = quote from respondent involved in production scheduling;

SS = quote from respondent involved in staff scheduling;

RP = quote from respondent involved in route planning.

Before moving on to introducing Study 2, a few discussion points and avenues for further research are briefly discussed. First, it can be questioned to what extent the performance criteria used in the firms actually fulfill the requirements for good metrics (Neely et al. 1997; Melnyk et al. 2004; Lehtinen and Ahola 2010). For instance, Neely et al. (1997) stated, "one of the golden rules of performance measurement is that there is no point measuring someone on something over which they have no control" (p. 1139). As noted earlier, some of the criteria discussed above were related to processes over which the schedulers had no control. For instance, many processes and people that are beyond the scope of the scheduler will influence the final costs of the scheduled process. Thus, using these costs to assess scheduling performance violates the golden rule easily. Therefore, further research is needed to develop valid and useful metrics for measuring scheduling performance in practice. Interestingly, similar discussions about the need for appropriate performance portfolios are found in studies investigating performance measurement on the strategic and tactical planning levels (Evans 2004; Melnyk et al. 2004; Papke-Shields et al. 2006; Bendoly et al. 2007; Jonsson and Mattsson 2008). Our results show there is also a need to develop such performance portfolios for the operational planning and scheduling level. In addition, we see a need for research that carefully aligns the performance measurement systems for the different levels of planning and scheduling.

Second, the findings clearly showed that scheduling performance is a multidimensional concept and, therefore, multidimensional measurement systems are needed. The classification of scheduling performance criteria in Figure 2.1 raises the issue of compatibility and trade-offs between the different types of scheduling performance measures. Performing well in terms of one criterion could imply performing less well in terms of another. For example, a high performance in terms of schedule execution cost could result in schedulers requiring more time for puzzle solving activities, decreasing their performance in terms of speed and flexibility. In general, appropriate weightings for the various performance criteria will differ between firms, they can also change over time, and they can differ among the scheduled tasks and orders (Hsu 2006). In short, scheduling requires so-called 'balanced performance measurement systems' (Neely 2005) that provide managers with up-to-date and useful information for managing and improving scheduling performance.

Finally, here, the variety found among firms suggests that the relevance of the various performance criteria is dependent on the scheduling situation at hand. This issue is explored in Study 2 that provides a first step toward understanding the fit between organizational context and scheduling performance criteria.

2.4 Study 2: Identifying the link between context and performance

2.4.1 Background, theory and hypotheses

Our first study showed that firms use performance criteria focused on the schedule itself as well as on the scheduling process. Although many firms used both product- and process-oriented performance criteria, the relative importance of the two types varied between firms. Contingency theory (Drazin and Van der Ven 1985; Sousa and Voss 2008) suggests that some form of fit will exist between the scheduling context and the scheduling performance focus, be it on product performance or on process performance. The question arises as to which circumstances lead firms to focus mainly on product- or on process- oriented scheduling performance.

In the scheduling process, as discussed in Section 2.2, many kinds of information are processed. As such, scheduling can be viewed as a set of information processing activities. This information processing takes place under uncertainty. Many empirical studies have shown that the scheduler is often aware that the information will change and new information will have to be processed in the future (e.g., McKay et al. 1995a; MacCarthy and Wilson 2001). Information Processing Theory (IPT) argues that organizations "must develop

information processing mechanisms capable of dealing with both external and internal sources of uncertainty" (Tushman and Nadler 1978: 614). Increased information visibility and information exchange are aimed at reducing and coping with this uncertainty (Galbraith 1974). If there is no uncertainty, a task can be fully prescheduled, and execution can proceed without disruptions. However, if there is uncertainty, the organization and the processes should be designed and managed to cope with it (Thompson 1967; Sitkin et al. 1994). The literature shows that, in general, different practices and processes are needed to cope with different types and levels of uncertainty (Reed et al. 1996; Koufteros et al. 2002; Anand and Ward 2004). Building on IPT, Bendoly and Swink (2007) showed the importance of information availability in highly uncertain project scheduling environments. Information visibility appeared not only to affect immediate project timeliness, but also rational and non-rational human behavior. The relationship between the level of uncertainty and a firm's focus on scheduling performance is investigated by building on these studies in Study 2.

Essentially, research into scheduling suggests two mechanisms for dealing with uncertainty (Vieira et al. 2003; Aytug et al. 2005; Pinedo 2008). First, to avoid overloading schedulers with rescheduling requests, schedules should be resilient to small deviations by including buffers and slack (Van Landeghem and Vanmaele 2002; Herroelen and Leus 2005; Branke and Mattfeld 2005). For example, an order that is delayed by a few minutes does not need rescheduling because the machine operator can handle it without further problems. However, if the delay is longer and, because of that, an order cannot be finished on the same day, the schedulers will usually need to be involved to assess the consequences for the next day's plan. Thus, the second mechanism in dealing with uncertainty is adjusting the plan or schedule. Rescheduling or reactive scheduling adds two factors to scheduling: the available time to create the schedule is shorter, and ideally, the existing schedule should not change too much because this creates nervousness on the shop floor (Aytug et al. 2005). Many algorithms and heuristics have been developed to tackle rescheduling problems (Vieira et al. 2003). Both reactive and robust scheduling techniques presume that the scheduling problem can be formalized, that a best solution (given the time constraints) can be calculated, and that the schedule will then be executed (Hsu 2006). In many rescheduling studies, performance is assessed using similar measures to those in a normal scheduling situation: schedule-focused criteria such as minimization of tardiness, extra costs, or schedule changes are used (Vieira et al. 2003). However, our first study indicated various other performance criteria that also need attention. In uncertain scheduling situations, schedulers are frequently confronted with new and changing information that requires a responsive scheduling process. IPT suggests that, in

such uncertain situations, more information exchange is needed and, therefore, the performance of the scheduling *process* will be crucial. On this basis, it is hypothesized that the level of uncertainty is associated with a performance focus on scheduling process performance. Therefore, we hypothesize:

H1: Good scheduling process performance is more important in scheduling situations faced with high uncertainty than in scheduling situations faced with low uncertainty.

More in particular, according to IPT, operational uncertainty stems from two sources: internal factors and external factors (Tushman and Nadler 1978; Galbraith 2002; Field et al. 2005). Considering the scheduling process, Wäfler (2001) distinguishes two comparable sources of uncertainty that lead to information processing during a scheduler's task execution: environmental uncertainty and executional uncertainty. Changing information about what has to be scheduled, and about the constraints to be taken into account, causes environmental uncertainty; examples are rush orders, late delivery of raw material by suppliers, or new outsourcing opportunities. Executional uncertainty concerns uncertainty in the schedule execution process that prevents the schedule being executed exactly as intended (Aytug et al. 2005); examples are disruptions in production, shortage of raw material due to inventory miscalculations, traffic jams, and staff illness. The levels of environmental and executional uncertainty can be different within a particular scheduling situation; therefore, they are investigated separately. Both sources of uncertainty lead to schedules being frequently adapted, putting stringent requirements on the flexibility and speed of the scheduling process: a lot of information has to be processed in a short time. Therefore, two further hypotheses are formulated as:

H1a: The level of environmental uncertainty is higher in firms focusing on scheduling process performance than in firms focusing on scheduling product performance.

H1b: The level of executional uncertainty is higher in firms focusing on scheduling process performance than in firms focusing on scheduling product performance.

Figure 2.2 shows the variables and hypotheses considered in Study 2.

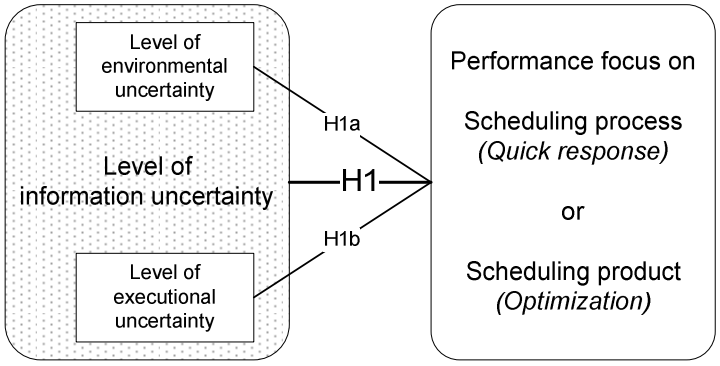

Figure 2.2 Research model for Study 2

2.4.2 Method

2.4.2.1 Sample and data collection

Whereas the research design used in Study 1 was exploratory in nature, in Study 2 an explanatory survey methodology (Malhotra and Grover 1998; Forza 2002) was selected to test the hypotheses. First, a random sample of almost 300 firms with different scheduling situations was approached by phone, and around half of them agreed to participate in our survey. In most cases, survey data were collected by phone to achieve a high response rate. If the respondent indicated to participate only if he could use a paper version, this was allowed. Then, a paper version was sent to the respondent with an explanatory note to ensure that all respondents had the same information about the questions. The ten researchers participating in the data collection process were trained and provided with a detailed survey protocol to prevent any bias. The protocol described the project objectives, highlighted several behavioral communication rules, and guided the researchers through the questions.

In total, 138 responses were collected. Several of the respondents were only employed part-time and to avoid responses involving frequencies being misinterpreted, it was decided to use only the data from respondents working at least 32 hours a week. After this filter, 125 responses remained covering a wide range of scheduling situations, including production, staff, transport, and project scheduling (Table 2.4).

Table 2.4 Cases in Study 2

Firm type	Number of cases	Production scheduling	Staff scheduling	Route planning	Project scheduling	Other scheduling
Manufacturing	24	17	1	3	2	1
Transportation	32	1	9	21	0	1
Service	69	11	39	2	15	2
Total	125	29	49	26	17	4

2.4.2.2 Measures

Performance focus. Study 1 provided an indication of what kinds of elements are embraced within scheduling product and scheduling process performance. Scheduling product performance appeared to be mainly determined by how well internal and external constraints were fulfilled. Scheduling process performance appeared to be mainly determined by the reliability, flexibility, response speed, and communication and harmonization capabilities of the schedulers. Given these findings, it was decided to formulate a binary question through which the relative importance of scheduling product performance to scheduling process performance could be assessed. The informants were asked to indicate which was more important in their situation: 'a quick response' or 'schedule optimization'. Although the use of separate questions with Likert-type scales to indicate the importance of particular performance criteria was considered, this approach was rejected due to the resulting common methodological problems related to comparing different categories. Given the nature of the study, the use of a straightforward dichotomy to measure performance focus was adequate.

Information uncertainty. The level of information uncertainty was measured in two ways. First, the schedulers' perception of information uncertainty was measured. Respondents were asked to indicate the level of information uncertainty through an either/or question: 'Is information uncertain and continuously changing, or is information available and barely changing'. Second, uncertainty was measured by asking respondents to assess the intensity of information flows using two frequency measures. In information processing theory, uncertainty has been defined as "the difference between information possessed and information required to complete a task" (Tushman and Nadler 1978: 615). On this basis, executional uncertainty was operationalized as the frequency of feedback from the schedule users to the scheduler, and environmental uncertainty as the frequency of new information being delivered to the scheduler (after the schedule has been released) from others than the users of the schedule. Both frequencies were measured using a six-point ordinal scale: (1) never, (2) rarely (less than once a week), (3) 1-4 times a week, (4) 1-5 times a day, (5) 6-20 times a day, and (6) more than 20 times a day.

To assess the internal coherence between these two methods of measuring uncertainty, the relationships between the perceived level of uncertainty and the average frequencies of feedback and of receiving new information from others were investigated. Results from a Mann Whitney *U* test indicated that when information is perceived as highly uncertain (n_{high}), the feedback frequencies were significantly higher than in situations with low perceived

information uncertainty (n_{low}) (n_{high} = 75, n_{low} = 46, U = 1370, z = -1.972, $p < .05$). Similar results were found regarding the frequency of receiving new information from others (n_{high} = 73, n_{low} = 45, U = 852, z = -4.494, $p < .001$). As expected, and in line with IPT, information flows become more frequent as uncertainty increases. These results confirm the validity of the methods proposed for measuring uncertainty in order to test the hypotheses.

2.4.3 Results

Forty-five percent of the respondents indicated that they find a quick response more important than an optimized solution. Delivering a quick response requires the ability to flexibly communicate, negotiate, and make and adapt scheduling decisions. As such, this high percentage alone is sufficient to justify the relevance of giving theoretical and managerial attention to the design, organization, and management of the scheduling process. Figure 2.3 displays the percentages of respondents who prefer a quick response as against optimization in situations of low and high information uncertainty. Even when information uncertainty was low, almost one-third of the respondents still responded that they found a 'quick response' to be more important than 'optimization'. Therefore, this figure provides additional support for the main finding in Study 1, that many schedulers consider the process aspects of scheduling to be important. In this way, the results show the relevance of giving theoretical and managerial attention to optimization as well as to the design, organization, and management of the scheduling process.

Figure 2.3 suggests a pattern between the level of information uncertainty and the performance focus: if uncertainty is high, a higher percentage of respondents prefer a quick response over an optimized solution (54% versus 46%), and if uncertainty is low, more organizations focus on optimization than on a fast response (69% versus 31%). The chi-square test indicates a significant difference in the performance focus distribution between the two groups with a high and low level of information uncertainty (χ^2 = 6.12, $p < .05$). Therefore, it can be concluded that the (perceived) level of information uncertainty influences the preference for either a quick response or an optimized solution. Thus, Hypothesis 1 is supported.

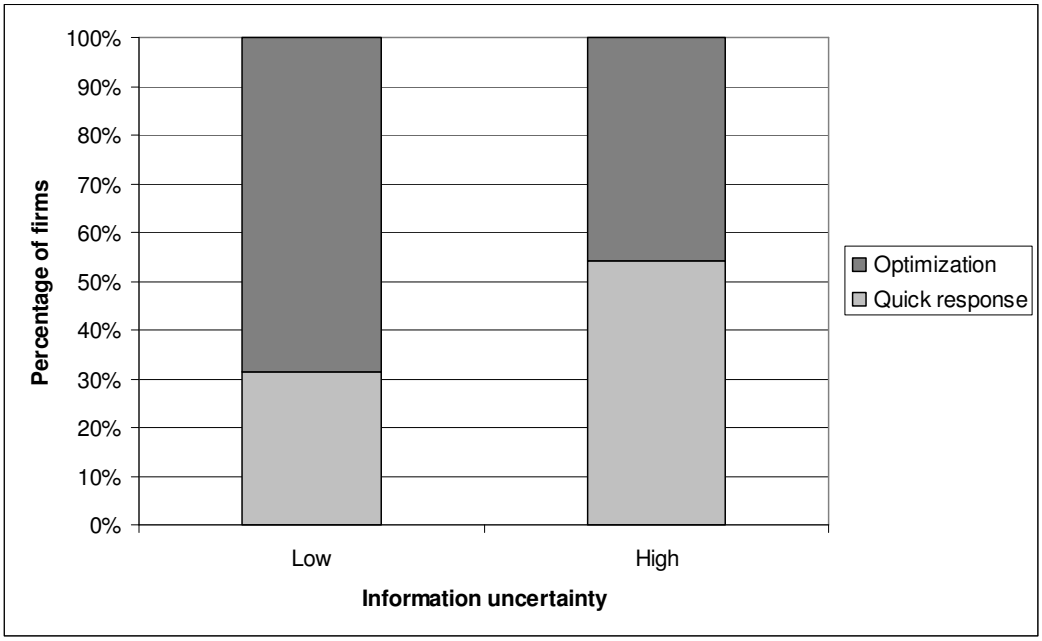

Figure 2.3 Performance focus and information uncertainty

To investigate whether the source of uncertainty relates to the performance focus, i.e., the more detailed hypotheses 1a and 1b, the Mann Whitney *U* test was used to test for differences between firms showing a performance preference for optimization (n_{opt}) and firms with a performance preference for a quick response (n_{resp}). The average frequency of new environmental information is significantly higher in firms preferring a quick response to those in companies favoring optimization ($n_{resp} = 53$, $n_{opt} = 63$, $U = 839$, $z = -4.732$, $p < .001$). Similarly, the average feedback frequency is significantly higher from schedule users in firms preferring a quick response to those in companies favoring optimization ($n_{resp} = 54$, $n_{opt} = 65$, $U = 1402$, $z = -1.963$, $p = .050$). Hypotheses 1a and 1b are therefore supported: higher levels of environmental uncertainty and executional uncertainty go together with a performance focus on the scheduling process rather than the scheduling product.

2.4.4 Summary and discussion

In Study 2, the conditional influence of uncertainty on a firm's focus in scheduling performance has been investigated. Within the sample, almost half of the respondents indicated that, in their scheduling situations, responsiveness was more important than optimization of the schedule. Of course, this result does not imply that schedulers do not, or should not, strive for optimization; rather, the conclusion is that optimization is not the only,

and in many cases not even the most important, performance criterion for schedulers. The findings show that especially in situations with high information uncertainty the performance of the scheduling process is more important than the performance of the scheduling product. A few explanations for these findings are briefly elaborated below.

First, feedback from those employees executing the schedule provides the scheduler with information about practical infeasibilities in the schedule. Sometimes, schedule users can adapt the schedule themselves; and then schedulers will focus on schedule robustness to minimize the effort required to adapt the schedule. However, in many situations, the schedule users are not able and/or not allowed to adjust the schedule by themselves: the scheduler has to be informed and asked to adapt the schedule. In such circumstances, a quick response is more important than providing optimized schedules. As such, executional uncertainty and high scheduling process performance are related.

Second, the findings indicate that a high frequency of new information coming from outside the departments that execute the schedule also requires schedulers to respond quickly rather than to focus on optimization. Such information will not always influence the schedule feasibility directly, and the information processing could result in a decision not to change the schedule (for instance, if the opportunity to fit in a rush order was investigated but rejected). Nevertheless, schedulers indicate that responsiveness in such situations is highly important. In this way, our results extend the findings of Van Wezel et al. (2006b) showing the importance of planning process flexibility in the food processing industry, and of Zwikael and Sadeh (2007) demonstrating how schedule adaptation improves project-scheduling performance.

Further, the results provide support for the earlier empirical case studies that highlighted the important role of schedulers as indispensable information processing actors in scheduling and rescheduling (McKay et al. 1995a; MacCarthy and Wilson 2001; Jackson et al. 2004; Fransoo and Wiers 2006). Finally, whereas uncertainty has been advocated as a relevant contingency factor within business performance and quality management in general (Anand and Ward 2004; Field et al. 2005; Sousa and Voss 2008), our findings demonstrate the impact of internal and external uncertainty on scheduling performance preferences.

Several limitations in the study must be acknowledged. First, the aim of Study 2 was to understand when process-related performance criteria are important. This question was approached using theories about uncertainty and the role of information flows in dealing with this uncertainty. Other variables that could influence a firm's performance focus were neglected here; clearly, these factors need to be addressed in further research. Second, a

distinction has been made between two, clearly different, performance foci: responsiveness and optimization. In practice, other performance dimensions will also be present and relevant. Although establishing a dichotomy between process- and product- oriented performance foci was helpful in this study, it does not do justice to the complexity and variety found in scheduling performance in reality. Building upon our two studies, further research is planned that will measure scheduling performance more completely. Finally, our sample, while heterogeneous, was still relatively small and cannot be used to generalize to the total population of planning and scheduling situations. Therefore, the research should be seen as being more suited to building theory than for making (grounded) prescriptions for practice. Before making such prescriptions, many more data need to be collected and analyzed.

2.5 Conclusions

In many firms, scheduling occurs in a dynamic organizational context. This chapter has shown how firms handle this context in assessing scheduling performance. Alongside well-known scheduling *product* performance criteria, such as the number and severity of constraint violations and resource utilization rates, it has been shown that most firms also use scheduling *process* performance metrics such as responsiveness and the flexibility of schedulers. Moreover, the analysis has shown that responsiveness appeared to be especially important in scheduling situations with high levels of information uncertainty. These findings have important implications for both scheduling theory and scheduling practice.

In planning and scheduling theory, the dominant focus is on the development of advanced algorithms, heuristics, and systems that can solve all kinds of scheduling problems. These techniques and systems can significantly contribute to enhancing scheduling performance. However, several related issues in scheduling need also to be addressed in theory. First, the findings from this research indicate that scheduling performance is determined by a variety of product and process criteria that are potentially conflicting, and that the organizational context of scheduling should be considered in determining the relative importance of performance criteria. Second, the relative importance of the performance of the scheduling process as against the performance of the scheduling product will have consequences for the organizational design and management of the scheduling function within a firm. Third, in scheduling situations characterized by high uncertainty, schedulers should be supported in different ways than in situations characterized by low uncertainty. Accordingly, our findings suggest interesting opportunities to investigate appropriate means of organizing and

managing scheduling that are contingent with the scheduling context. Here, well established insights and methods from contingency and organizational configuration research (Drazin and Van der Ven 1985; Short et al. 2008; Sousa and Voss 2008) could be used to investigate those particularly relevant questions within the planning and scheduling domain.

Principles, practices, as well as techniques for measuring scheduling performance in practice have been addressed in this chapter, and an initial categorization of scheduling performance criteria has been proposed. Figure 2.4 presents a scheduling performance focus matrix based on the outcomes of both studies. The matrix shows the relatively decreasing importance of scheduling product performance criteria and the relatively increasing importance of scheduling process performance criteria if uncertainty increases. Further empirical research is required to establish in more detail the importance of the various performance measures and their relation to uncertainty or other contingency factors. Based on such studies, performance management systems for scheduling that enable the efficient reporting of performance information followed by appropriate improvement actions could be developed in future research.

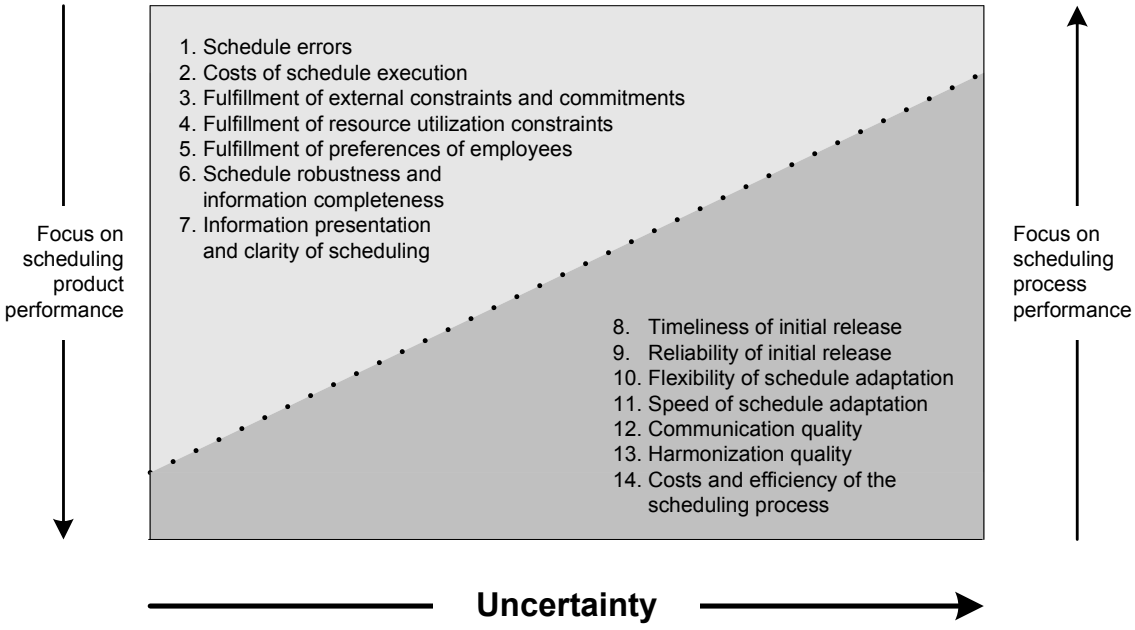

Figure 2.4 Scheduling performance focus matrix

For practitioners, the findings from our studies suggest the need for a broad managerial view on the determinants of scheduling performance. More specifically, the findings show that scheduling performance is determined by both the quality of the scheduling process as

well as the quality of the schedules. Therefore, to improve scheduling performance, a sole focus on methods to improve schedule quality, for example by using complex and expensive software systems, is not appropriate. Rather, managers also need to consider also the organizational process of scheduling, including the schedulers' job criteria, the allocation of scheduling tasks and responsibilities, the design of coordination mechanisms and information systems, and the educational and training needs of schedulers. The proposed framework of scheduling performance measures provides a guide for distinguishing and selecting firm-specific performance measures. Further, the results make clear that scheduling process performance particularly requires managerial attention in dynamic, highly uncertain scheduling situations. In sum, to improve scheduling performance, a true understanding of the role and contribution of the scheduling function within the firm is required including the performance measures to assess this contribution.

APPENDIX 2A: Research Methods: Study 1

2A-I: Exploratory survey topics used in Phase 1

For the scheduler:

1. Description of job function and scheduling situation (scheduled objects, frequency of scheduling and rescheduling, relation between (sub-)schedules, use of IT).
2. Performance criteria that the schedules should satisfy and the way these criteria are measured.
3. (Organizational) variables influencing the scheduling performance.
4. Possibilities to improve scheduling performance.
5. The opinion of schedule users and of the management about the output of the scheduling.

For the manager:

6. Description of firm and business process that is scheduled by the scheduler.
7. Objectives and (formal) responsibility for the schedules. Decision latitude for the scheduler and negotiation procedures.
8. Criteria that the schedules should satisfy and effects of low quality plans on the objectives of the scheduled process.
9. The opinion of schedule users about the output of the scheduling (if known).
10. The policies to evaluate, retain, and/or improve the quality of the schedules (if available).
11. Possibilities to improve scheduling performance.
12. Problems with scheduling.

2A-II: Descriptive survey questions used in Phase 2

The same interview guidelines were used for the scheduler and for the schedule user. Although only a small number of questions were formulated in advance, the interviewers were instructed to probe all interviewees thoroughly.

1. Please describe your job function.
2. What do you consider good or bad scheduling?
3. Can you provide an example of good / bad scheduling?
4. Which criteria do you use to judge or evaluate scheduling performance?
5. How and when do you judge scheduling?
6. What do you think your manager considers good / bad scheduling?
7. What do you think the employees who use the schedules find good / bad scheduling?

APPENDIX 2B: Detailed overview of cases used in Study 1

	Nr.	Type of organization	Production scheduling	Staff scheduling	Route planning
Phase 1 - Exploratory survey	1	Bank		x	
	2	Dredging company		x	
	3	Limestone manufacturer	x		
	4	Electronics manufacturer	x		
	5	Steel manufacturer	x		
	6	Airconditioning manufacturer	x		
	7	Steel and pipes manufacturer	x		
	8	Callcenter		x	
	9	Manufacturer of carton packaging	x		
	10	Building firm	x	x	x
	11	Public transport company	x		x
	12	Public transport company		x	
	13	Metal processing firm	x		x
	14	Office furniture manufacturer	x		x
	15	Machine manufacturer	x		
	16	Private transport company	x	x	
	17	Motion and control system manufacturer	x		
	18	Callcenter		x	
	19	Public transport company		x	
	20	Callcenter	x	x	
	21	Public transport company		x	x
	22	Mail ordering system manufacturer	x		
	23	Office furniture manufacturer	x		
	24	Public transport company	x	x	x
	25	Engineering firm	x		
	26	Steel manufacturer	x		
	27	Meeting center	x		
	28	Maritime pilot organization		x	
	29	Storage provider for bulk liquids	x	x	
	30	Ship building firm	x		
	31	Ship maintenance firm	x		
	32	Manufacturer of ship installations	x		
Phase 2 - Descriptive survey	33	Road service agency		x	x
	34	Amusement park		x	
	35	Casino		x	
	36	Shaver manufacturer	x		
	37	Care agency call center		x	
	38	Manufacturer of potato starch	x		x
	39	Pipe manufacturer	x		
	40	Public transport company		x	x
	41	Rehabilitation center	x	x	
	42	Airline company	x	x	
	43	Home care organization	x	x	

APPENDIX 2C: Quotes from Study 1 Phase 2 on scheduling performance

Nr.	Firm	Respondent	Criteria on scheduling product	Other scheduling performance criteria	Factors influencing scheduling performance	Other significant quotes
33	**Road service agency**	Staff and route scheduler	* Guidelines I have to obey include: - the driving time of the road service employee should not exceed 30 minutes; - the waiting time for the client should not exceed 90 minutes; - urgent situations and priorities have to be processed first.	* Situations should be solved on time (scheduling performs badly if situations are not solved in a timely way). * Even if there are many rescheduling problems, the plan quality is still sufficient if the plan users understand the situation and solutions. * Good scheduling results in an acceptable situation for the plan users. * Good scheduling means no problems in the areas of other planners (e.g., because of using their resources).	* The road service employees influence the planning enormously, and human processing times are difficult to estimate. * In the past, the schedulers had the authority to prescribe an employee's plan (e.g., when he had to leave or end a job). Now, employees may decide this for themselves; therefore, it has become more difficult for schedulers to estimate processing times and routes. * 70% of the work is done by the computer; some schedulers think that they can realize better plans than the computer; however, 9 out of 10 mistakes are caused by humans... * More rules (i.e., less decision latitude) for the plan users would improve the scheduling quality.	* Norms are difficult to reach, because you have little influence on the parties you work with. * Good planning differs from time to time. I have to balance various interests, while choosing the least bad solution. * Good scheduling is highly dependent on the environment: I am satisfied with the scheduling quality if I have reasonably dealt with all the problems, even if norms have had to be violated. * Scheduling performance should be measured over a longer time, because the situation can change every five minutes.
		Road service employee	* Good scheduling leads to short waiting times for the clients.	* Scheduling performance is evaluated by my manager based on the average processing time per job and the number of finished jobs per road service employee.	* Scheduling performance should improve if the planner could change the computer plan proposals. * Regular work meetings between the planner and plan users improved their mutual understanding and decreased the level of irritation of plan users. * The planning could be improved if somewhat more information was given about the open jobs (e.g., characteristics of car failures). This would enable the employee to better assess/balance the necessary effort/time he/she will spend per client.	-

APPENDIX 2C (continued): Quotes from Study 1 Phase 2 on scheduling performance

Nr.	Firm	Respondent	Criteria on scheduling product	Other scheduling performance criteria	Factors influencing scheduling performance	Other significant quotes
34	**Amusement park**	Manager of planning office	* Shifts have to be filled as much as possible. * Preferences of employees have to be taken into account. * Fixed-contract employees should not be scheduled on shifts for temporary employees (to avoid high costs). * Employees should not be allocated to too many shifts, because they can claim this as overtime later. * An acceptable plan deviates from a good plan by a maximum of 5%. * The operations manager judges the planning on costs and on fulfillment of safety requirements.	* The planning is bad when planners do not listen to their manager. * Planning performance is assessed on the staff costs during plan execution, and on the number of complaints that I receive from planned employees. * If the manager of the planned department is satisfied, the planning quality is deemed good. * The operations manager judges the planning also on complaints of employees, and complaints of visitors/clients. * I judge the planning based on messages from the planners and the departmental managers. In addition, I judge it based on complaints from the employees themselves. This is more based on feeling than on numbers.	* Information about staff availability should be present on time. For instance, if data about educational duties become available too late, plans have to be changed after release, and the planning can never become as good as before. * There are too many constraints (e.g., safety requirements, maximum budget, and maximum number of temporary personnel).	* Fulfilling all job qualifications does not guarantee a good execution of the staff schedule. For instance, one duo can form a 'dream team', whereas another duo cannot collaborate at all. Thus, the planner has to take into account human characteristics alongside basic qualifications.
		All-round employee	* Good scheduling equals taking into account the wishes of the employee.	* Good scheduling equals coordination, as much as possible, with the scheduled employees, especially in case of plan changes.	-	-
35	**Casino**	Staff scheduler	* Good scheduling amounts to a fit between required capacity and planned capacity (i.e., no shortage or surplus of human capacity). * The scheduling manager judges the scheduling quality on the use of rights (employees should not get too many/too few rights on day offs etc.) and the spreading of holidays.	-	* When the released schedule is not feasible, you are always catching up with the facts. * Cooperative employees get more wishes realized than employees who are stiff and surly.	* Signals from several employees about a single problematic aspect in the schedule will result in some action.
		Croupier	* Good scheduling is having sufficient employees for the tasks to be done.	-	* The scheduling quality could be improved if employees had more opportunities to indicate their preferences regarding days off and compensation days.	* The schedule is always good, because it is released so early (six weeks before realization). * It is positive that employees can change shifts.

APPENDIX 2C (continued): Quotes from Study 1 Phase 2 on scheduling performance

Nr.	Firm	Respondent	Criteria on scheduling product	Other scheduling performance criteria	Factors influencing scheduling performance	Other significant quotes
36	**Manufacturer of shavers**	Production planner	* Satisfy production constraints (equalize workload per line, use available capacities, use few setups, satisfy sales). * Wishes of production should be taken into account.	* Plans should not change too often (this results in problems for the purchasing department especially). * The planning quality is good if the plan is accepted by production without grumbling.	* If a supplier cannot deliver material, the planning quality decreases, because the plan is not reliable (no stable production).	* If suppliers could always deliver and if there were few constraints and restrictions on the production of different products, it would be the most beautiful situation. Little uncertainty results in few plan changes…
		Production line manager	* Fluctuations in demand should remain within 10% because of the staff costs of hiring and firing temporary personnel - the planning should be stable over time.	-	* If sales forecasts are incorrect, stable production is not possible.	-
37	**Care agency (call center department for health care questions)**	Staff scheduler	* Satisfy rules and agreements (e.g., variety of shifts, sufficient capacity per 30 minutes, appropriate solutions for peak hours). * Wishes of employees should be taken into account.	-	* Too many wishes from the staff complicate the development of a feasible schedule. Therefore, the possibilities for wishes have recently been reduced: each employee can announce one fixed wish per week and four flexible wishes per four weeks (day off, leave, training, etc.).	-
		Nurse	* Good scheduling is a good mix between days working and days off. Bad scheduling is having too few employees scheduled.	* Bad scheduling is having too many clients in the queue or long waiting times for clients.	-	-
38	**Manufacturer of potato starch**	Production scheduler	* Scheduling performance is assessed on the scheduled sequence of production activities (to avoid setups, slow moving stock, and product rejects) and on the anticipated delivery reliability and costs.	-	* Reliability of forecasts and the quality and quantity of the production output influence scheduling performance.	-
		Employee in logistics	-	* Quality of scheduling is judged on delivery reliability, calmness (few changes), and low costs.	* The right information should be delivered to enable actors to make decisions and to prevent unnecessary discussions.	* Good planning occurs if the planner has the right focus (e.g., business planning should not be involved in operations planning).

APPENDIX 2C (continued): Quotes from Study 1 Phase 2 on scheduling performance

Nr.	Firm	Respondent	Criteria on scheduling product	Other scheduling performance criteria	Factors influencing scheduling performance	Other significant quotes
39	**Manufacturer of pipes**	Production scheduler	* Criteria used include delivery times, stock levels, and setup times for machines. * Good scheduling amounts to clarity (the plan provides information about choices made by the scheduler) and correctness (e.g., correct estimation of job processing times). * Scheduling performance is influenced by the utilization rates of machines, people, and materials.	* The schedule should be available on time. * The schedulers should provide information about their choices (this increases the understanding and support for the scheduling). * Sales judge the scheduling quality on order delivery reliability; production judges if the schedules are feasible for the production operators; the planning manager judges operationally: are all tasks executed.	* Scheduling performance is also influenced by the characteristics of the planner (communication skills, tact, the ability to balance/communicate interests).	-
		Manager sales & planning	* Good scheduling is making optimal use of resources. * The operators judge the scheduling performance on the number of setups.	* The scheduling performance is judged on the collaborative behavior of the planner (with production); the transferability of the planner's tasks; the correctness of data; the extent of correct rejection of orders, and the stability of schedules. * The operators judge the scheduling performance also on the level of 'challenge' in the work, the number of plan changes, and the time pressure. * Good scheduling leads to satisfied clients.	The scheduler needs clear performance guidelines; it is bad if he/she is judged on flexibility whereas it was agreed that he/she would be assessed on production quantity. Performance criteria should be mutually understandable and consequent.	* Production performance indicators and planning performance indicators are mixed up a bit here. A production indicator is of course not a planning indicator. Because quantitative measures are lacking, I qualitatively judge scheduling performance with the following questions: - Is the scheduler communicating correctly? - Does the scheduler collaborate with production? - Does an overall view exist? - Are the tasks of the scheduler transferable? - Are production parameters and article data correct?

APPENDIX 2C (continued): Quotes from Study 1 Phase 2 on scheduling performance

Nr.	Firm	Respondent	Criteria on scheduling product	Other scheduling performance criteria	Factors influencing scheduling performance	Other significant quotes
40	**Public transport provider**	Staff and route schedulers	* Aspects considered include: all trips scheduled, budget, wishes of employees, labor rules, driving norms, controllability, and reliability of the planning.	* Good scheduling amounts to few complaints from employees.	-	-
		Manager tram department and manager main office	* Good scheduling is a schedule that is within constraints regarding shifts, vehicles, budget, etc.	* Scheduling performance is high if the timeline is followed precisely: information is communicated timely to employees, schedules are released timely, and schedules are reliable.	-	-
		Manager of bus drivers	* Good scheduling amounts to a match between demand and supply. Good schedules fulfill labor rules and norms, and are focused on efficiency (overtime and hiring in of extra personnel).	* Scheduling performance is dependent on the satisfaction of the employees (e.g., to what extent are their preferences and constraints taken into account, and what is the level of absenteeism). * Scheduling performance has to do with reliability (similarity between schedule and realization).	-	-
41	**Rehabilitation center**	Staff and patient scheduler	The schedules should enable: - a good program for the client - work variety for the doctor - sufficient patients to realize targets - short waiting queues - high utilization rate of doctors.	* Scheduling performance includes the speed of plan adaptation. * The quality of scheduling is judged on the number of phone calls, emails, questions, and complaints about the scheduling.	* Insight into the availability and capacity requirements of doctors and a bird's-eye view enable high quality scheduling. * The short planning horizon leads to many last-minute adaptations, no-shows, etc.	* Good scheduling means realizing a balance between the interests of client, doctor, and management.
		Manager of schedulers	-	* The schedules should be developed within time and efficiently. The scheduling process should be transparent (who does what; what can be expected from the schedulers). * The quality of scheduling is good if the client is satisfied (i.e., the client judges the program to be a good investment of their time, the program is not fragmented).	* Many parties provide information to the scheduler; the probability for making mistakes is high. * Who is the owner of the scheduling process: the scheduling department has the best overview, but has it also sufficient power and authority?	* The quality of scheduling is good if the plan is made efficiently (not too much/little time spent on scheduling). You can continue to optimize endlessly. But does the scheduler discover opportunities; are these used optimally?
		Manager of rehabilitation department	* Good schedules are ones that fit, as closely as possible, with the treatment protocol for the client.	* At this moment, I judge the scheduling quality as a 6, based on the number of complaints from doctors and clients.	* There are many informal old rules influencing the scheduling. A clear vision is lacking.	* Other parties are hindered if we have unreliable scheduling.

APPENDIX 2C (continued): Quotes from Study 1 Phase 2 on scheduling performance

Nr.	Firm	Respondent	Criteria on scheduling product	Other scheduling performance criteria	Factors influencing scheduling performance	Other significant quotes
42	**Airline company**	Staff schedulers	* Important criteria include the correct balance between tasks and rest intervals for the employees, employees' wishes are taken into account and capacity is used efficiently.	* Flexibility (the plan should be adaptable). * Scheduling should be reliable (one should hold to the agreements (currently, employees have trouble scheduling their private life).	* Insufficient clarity about priorities hinders the realization of high quality scheduling.	-
		Manager of schedulers	* Good scheduling is within budget and rules, and takes account of social aspects (wishes, sufficient job variation).	* Absenteeism rates due to employee dissatisfaction with the schedules are an indicator of scheduling quality.	-	-
43	**Home care organization**	Staff scheduler	* The employees find it important that their wishes are taken into account.	* The employees find it important that the plans are released timely. * Satisfaction of employees and satisfaction of clients are the most important aspects for the scheduler (including professionalism of care; good division of easy/heavy care tasks; short driving times).	-	-
		Directors + location manager	* The scheduling quality is measured by means of the following performance indicators: - % of deviations from preference day, margins of arrival time, preference employee, duration of care; - waiting time; - number and percentage of labor hours (fixed-contract employees, external employees and zero-hour contract employees); - number and percentage of labor hours for specific tasks; - fulfillment of wishes from clients; - budget deviations.	* The schedules should be developed as efficiently as possible.	-	-

APPENDIX 2D: Criteria mentioned by respondents in Study 1 Phase 1 (post analysis)

Nr.	Respon-dent	Criteria on the scheduling product							Criteria on the scheduling process							Indirect criteria		Factors influencing scheduling performance				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
		Schedule errors	Costs of execution of the schedule	Fulfillment of constraints made to 'external' parties	Fulfillment of resource utilization constraints	Fulfillment of preferences of employees using the schedules	Schedule robustness and information completeness	Information presentation and clarity	Timeliness of initial release	Reliability of initial release	Flexibility of schedule adaptation	Speed of schedule adaptation	Communication quality	Harmonization quality	Cost and efficiency of the scheduling process	Realized performance of the scheduled process	Complaints and feedback from schedule users	Planning structure	Scheduler's knowledge, skills and behavior	Availability and use of IT	Information availability, reliability and correctness	Scheduling complexity and uncertainty
1	Manager		x	x	x		x	x			x						x		x	x		
	Scheduler		x	x	x	x							x					x	x	x	x	
2	Manager		x	x	x												x					
	Scheduler		x	x	x						x	x	x		x	x			x	x	x	x
3	Manager		x	x	x				x							x						
	Scheduler	x		x	x										x	x		x		x	x	x
4	Manager	x		x	x		x				x					x		x				
	Scheduler			x	x		x							x		x		x	x	x	x	x
5	Manager			x	x												x	x			x	
	Scheduler			x	x											x			x	x	x	
6	Manager	x		x							x					x		x				
	Scheduler			x	x						x		x	x		x		x	x	x		
7	Manager			x	x								x	x				x		x	x	x
	Scheduler			x	x								x			x			x	x	x	
8	Manager			x	x	x										x	x	x		x		
	Scheduler			x	x	x					x		x			x	x		x	x	x	
9	Manager			x	x		x						x		x	x				x		
	Scheduler			x	x				x	x	x			x	x	x		x	x			
10	Manager			x																		
	Scheduler			x			x	x						x				x	x			
11	Manager		x		x						x	x						x				
	Scheduler	x	x	x	x		x						x	x		x			x	x	x	x
12	Manager		x		x				x		x		x				x	x	x			
	Scheduler		x	x	x									x					x			
13	Manager	x		x			x									x						
	Scheduler			x									x		x	x		x	x	x	x	
14	Manager				x								x						x			
	Scheduler				x													x	x			
15	Manager			x							x	x	x			x		x				
	Scheduler			x	x							x	x			x			x		x	x
16	Manager				x																	
	Scheduler		x		x								x						x			
17	Manager			x	x		x									x						
	Scheduler			x	x											x		x	x		x	
18	Manager		x	x	x	x							x							x		x
	Scheduler	x		x	x				x				x		x		x	x	x	x	x	
19	Manager		x	x	x	x							x					x				
	Scheduler	x		x	x	x					x	x	x					x	x		x	
20	Manager			x		x										x				x		
	Scheduler			x	x						x			x		x		x	x	x	x	
21	Manager		x	x	x				x						x	x		x		x		
	Scheduler	x	x	x	x								x	x	x	x		x	x	x	x	
22	Manager			x	x						x	x			x	x		x		x		x
	Scheduler			x					x		x	x				x		x		x	x	x
23	Manager			x												x		x		x		x
	Scheduler			x							x	x	x			x			x	x	x	
24	Manager	x	x	x	x	x																
	Scheduler	x	x	x	x	x							x					x	x	x		x
25	Manager	x		x	x		x									x		x		x		
	Scheduler	x		x	x		x		x				x						x		x	x
26	Manager		x	x	x						x			x				x				
	Scheduler	x					x	x		x			x					x			x	x
27	Manager			x	x													x				
	Scheduler	x	x	x	x		x		x		x	x	x						x			x
28	Manager	x		x	x	x							x	x				x	x	x		
	Scheduler			x	x								x			x					x	
29	Manager			x	x			x				x				x		x				
	Scheduler	x		x							x					x					x	x
30	Manager		x	x	x											x		x				x
	Scheduler			x																	x	
31	Manager		x	x	x									x	x	x		x				
	Scheduler	x			x		x											x				
32	Manager	x	x	x	x		x										x	x	x	x	x	
	Scheduler			x									x						x		x	x